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RESEARCH MEMORANDUM

AVERAGE SKIN-FRICTION COEFFICIENTS FROM BOUNDARY-LAYER MEASUREMENTS ON AN OGIVE-CYLINDER BODY IN FLIGHT AT SUPERSONIC SPEEDS

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AVERAGE SKIN-FRICTION COEFFICIENTS FROM BOUNDARY-LAYER MEASUREMENTS ON AN OGIVE-CYLINDER BODY IN FLIGHT AT SUPERSONIC SPEEDS

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SUMMARY

Boundary-layer measurements on a rocket-powered free-flight model to determine average skin-friction coefficients have been made on an ogive-cylinder body of fineness ratio 15.9. Average skin-friction coefficients were obtained for the body area ahead of the fins over a range of Mach number from 1.3 to 2.5 and over a range of Reynolds number from 90.3×10^6 to 162.9×10^6 (based on axial body length to the measurement station). Comparison of the experimental data with a flat-plate skin-friction theory by Van Driest showed good agreement.

INTRODUCTION

In estimating the total drag of supersonic missile configurations the accuracy of the skin-friction drag estimate is significant, since skin friction can account for as much as 50 percent of the total drag. Most of the widely known skin-friction theories (refs. 1, 2, and 3) are developed for flow on a flat plate; however, some calculations (ref. 4) to evaluate the effect of body shape on the turbulent skin friction indicate an almost negligible effect for bodies of high fineness ratio. The present paper presents average skin-friction coefficients as determined from boundary-layer total-pressure rake measurements using the boundary-layer momentum theorem. Rake measurements were made at the 124-inch station on a fin-stabilized ogive-cylinder body of fineness ratio 15.9. The cylindrical section extended approximately 10 body diameters ahead of the measurement station. The model was rocket-powered and the flight test was made at the Pilotless Aircraft Research Station at Wallops Island, Va.

Friction coefficients are presented over a Mach number range from 1.3 to 2.5 and over a Reynolds number range from 90.3×10^6 to 162.9×10^6

(based on axial body length to the measurement station). Results are compared with Van Driest's theory (ref. 2) for skin friction on a flat plate with heat transfer.

SYMBOLS

C_f	average skin-friction coefficient
M	Mach number
T_w	temperature of skin, °F abs
T_δ	temperature just outside boundary layer, °F abs
R	Reynolds number, based on axial body length
u	velocity within the boundary layer, fps

MODELS AND TESTS

The general configuration of the test model is shown in figure 1. The fuselage consisted of an ogival-nose section, a cylindrical center section, and a boattailed rear section and was made of 0.064-inch-thick duralumin skin with ring stiffeners. The fins were also of duralumin. The model skin was highly polished prior to flight testing.

The model was boosted with two ABL Deacon rocket motors which provided a total impulse of about 19,800 pound-seconds each, over a time of about 3.2 seconds. The sustainer motor within the model was a 65-inch-long HVAR with 7700 pound-seconds impulse.

A photograph of the model with booster just prior to launching is shown in figure 2.

The model was tracked by a CW Doppler velocimeter to obtain flight-path velocity. An SCR 584 radar set was used to obtain the flight path. Free-stream conditions of static pressure and temperature were obtained from flight-path and radiosonde data. The model was equipped with an NACA 10-channel tray-type telemeter. A six-tube total-pressure rake (fig. 3) was used to obtain the total pressure and, hence, the Mach number through the boundary layer. Free-stream static pressure was used as the static pressure at the rake station, since the measurement station was 10 body diameters from the nose tangency point. The model was also

assumed to be flying at zero angle of attack because of the large stability margin. The skin temperature at the measurement station was measured by a resistance-type temperature pickup (ref. 5) cemented to the inside surface of the 0.064-inch-thick duralumin skin. The sustainer rocket motor near the temperature pickup was covered with asbestos insulation to prevent heat flowing to the skin.

Data were obtained only during the powered part of the flight because of the failure of the model just prior to sustainer burnout.

RESULTS AND DISCUSSION

The skin-friction coefficients were obtained from boundary-layer total-pressure surveys and skin-temperature measurements. The Mach number distribution through the boundary layer was obtained from the total-pressure measurements and the local static pressure on the body which was assumed equal to measured free-stream static pressure. The Mach number distribution and temperature measurements were used with the Crocco temperature equation (ref. 6) to obtain a velocity and temperature variation through the boundary layer. The Crocco temperature equation was modified by a recovery factor of 0.89 to give a realistic value of adiabatic wall temperature at the skin rather than stagnation temperature. In reference 7 and in other references the value of 0.89 for the recovery factor has been found to be representative for turbulent flow. Shown in figure 4 are typical boundary-layer velocity profiles obtained for two of the test conditions. From the velocity and temperature distribution, the average skin-friction coefficient was obtained by use of the boundary-layer momentum theorem. The procedure for obtaining skin-friction coefficients from rake measurements is described in reference 8.

Time histories of the measured, average skin-friction coefficients for the area ahead of the measurement station and the average skin-friction coefficients predicted by the Van Driest theory are shown in figure 5 for the test Reynolds numbers, Mach numbers, and heating conditions. Also shown in figure 5 are time histories of Mach number, Reynolds number, T_W, and T_W/T_δ. Also shown on the plot of T_W/T_δ are the values which would have existed for an insulated wall condition. Although the cooling condition tends to raise the skin friction, the high Mach numbers of the test bring the measured friction values below those for incompressible flow at comparable Reynolds numbers.

The maximum difference between the experimental points and the Van Driest theory is about 8 percent, with excellent agreement shown over most of the range of test data.

CONCLUDING REMARKS

Average skin-friction coefficients have been measured on an ogive-cylinder body over a Mach number range from 1.3 to 2.5 and a Reynolds number range from 90.3×10^6 to 162.9×10^6. The experimental skin-friction coefficients were in good agreement with a flat-plate skin-friction theory by Van Driest.

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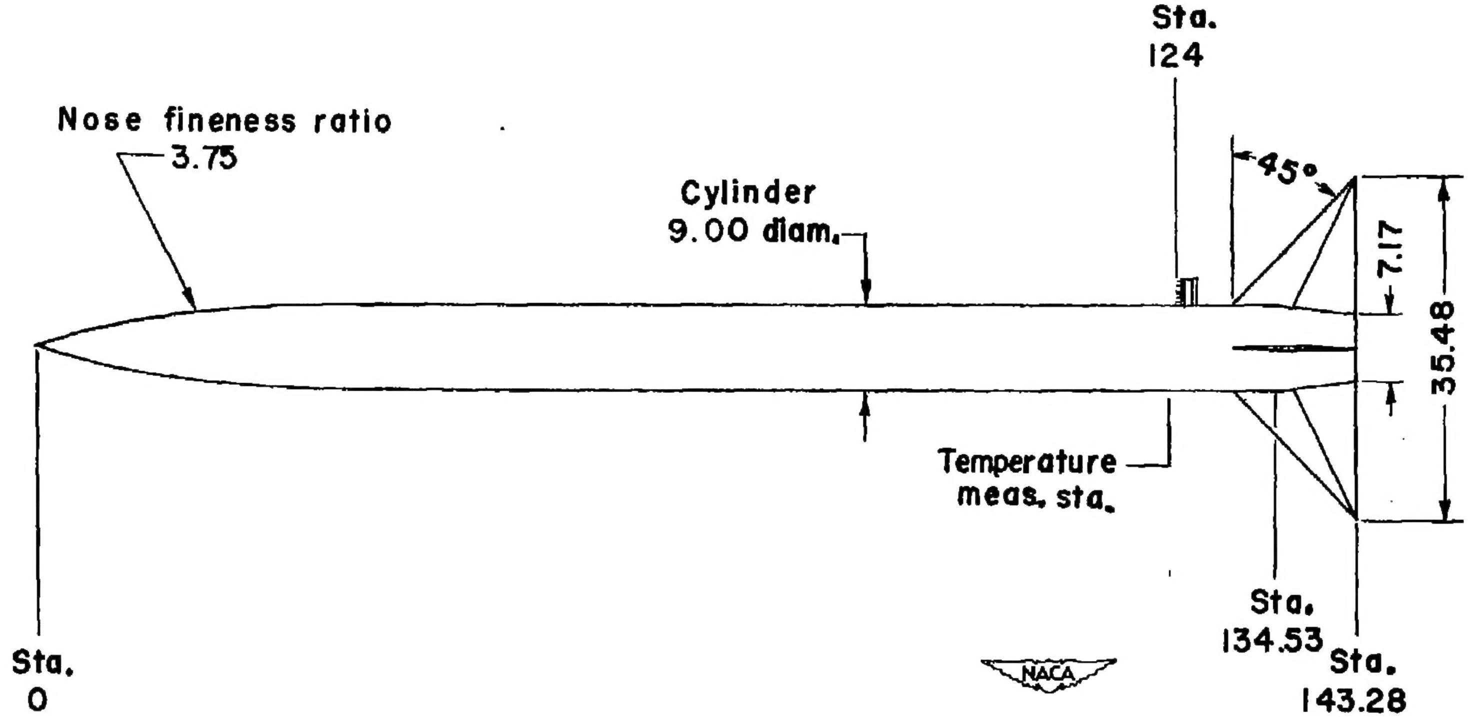

Figure 1.- General configuration of test model. Dimensions are in inches.

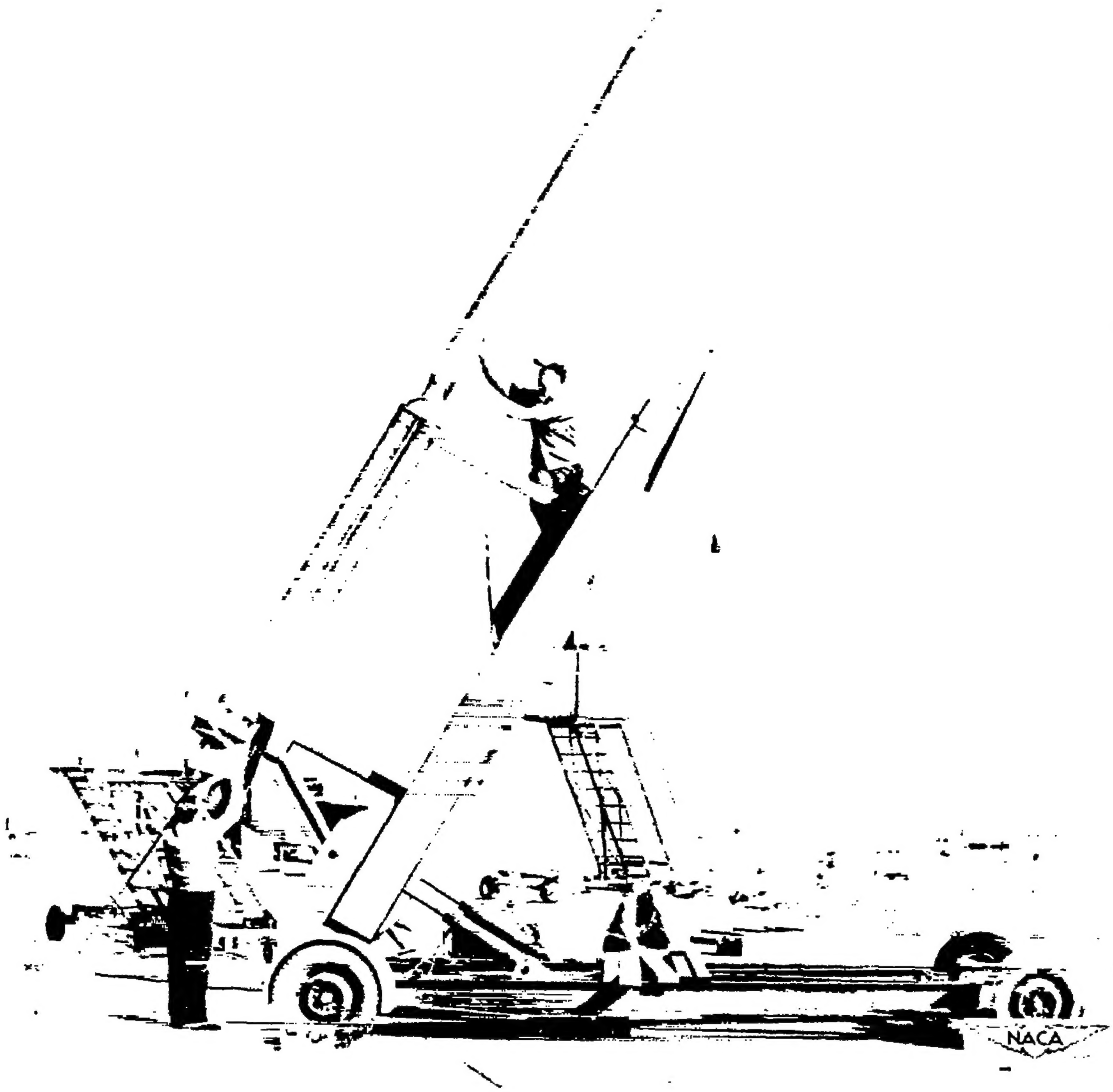

Figure 2.- Test model in launching position.

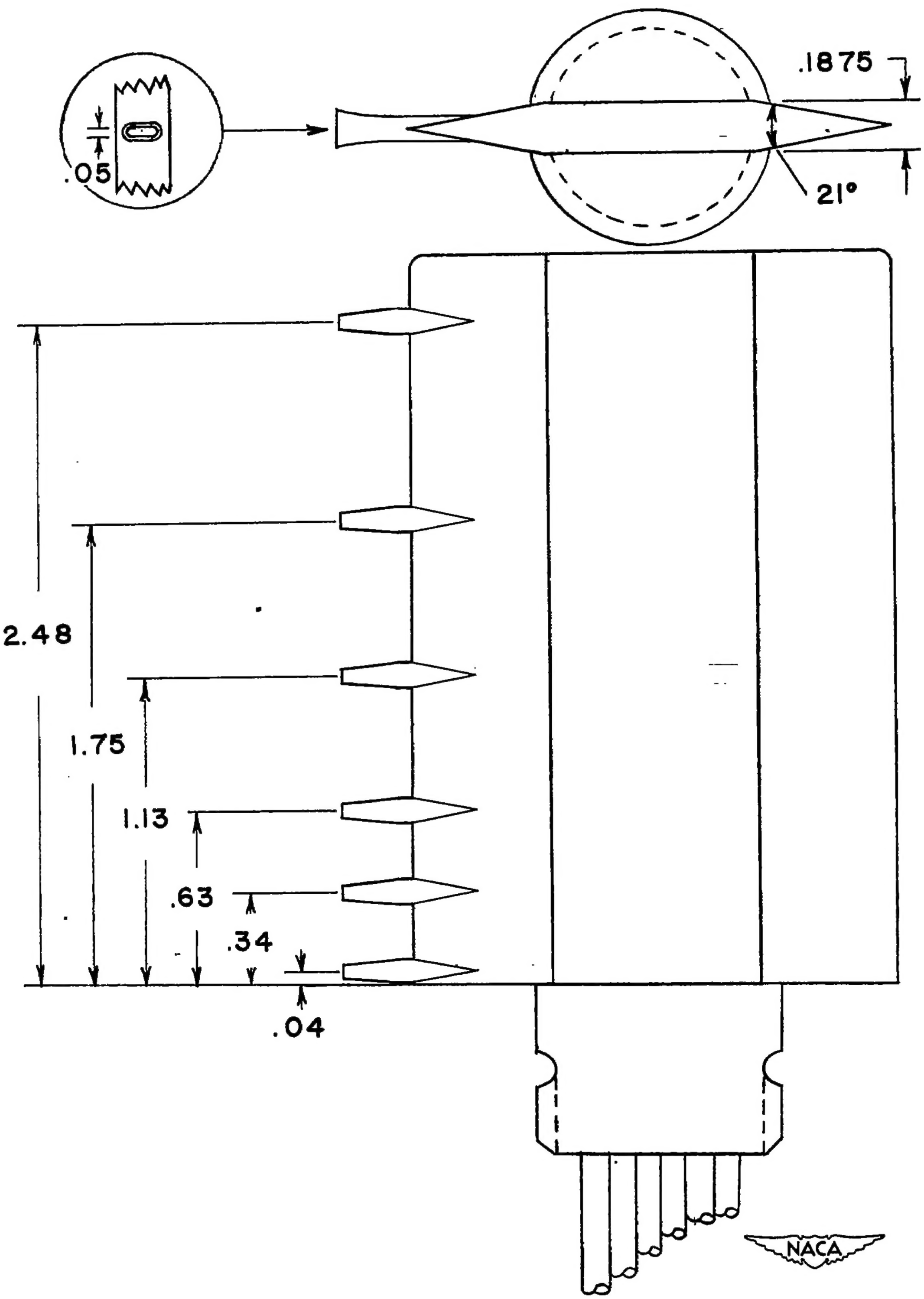

Figure 3.- Configuration of total-pressure rake. Dimensions are in inches.

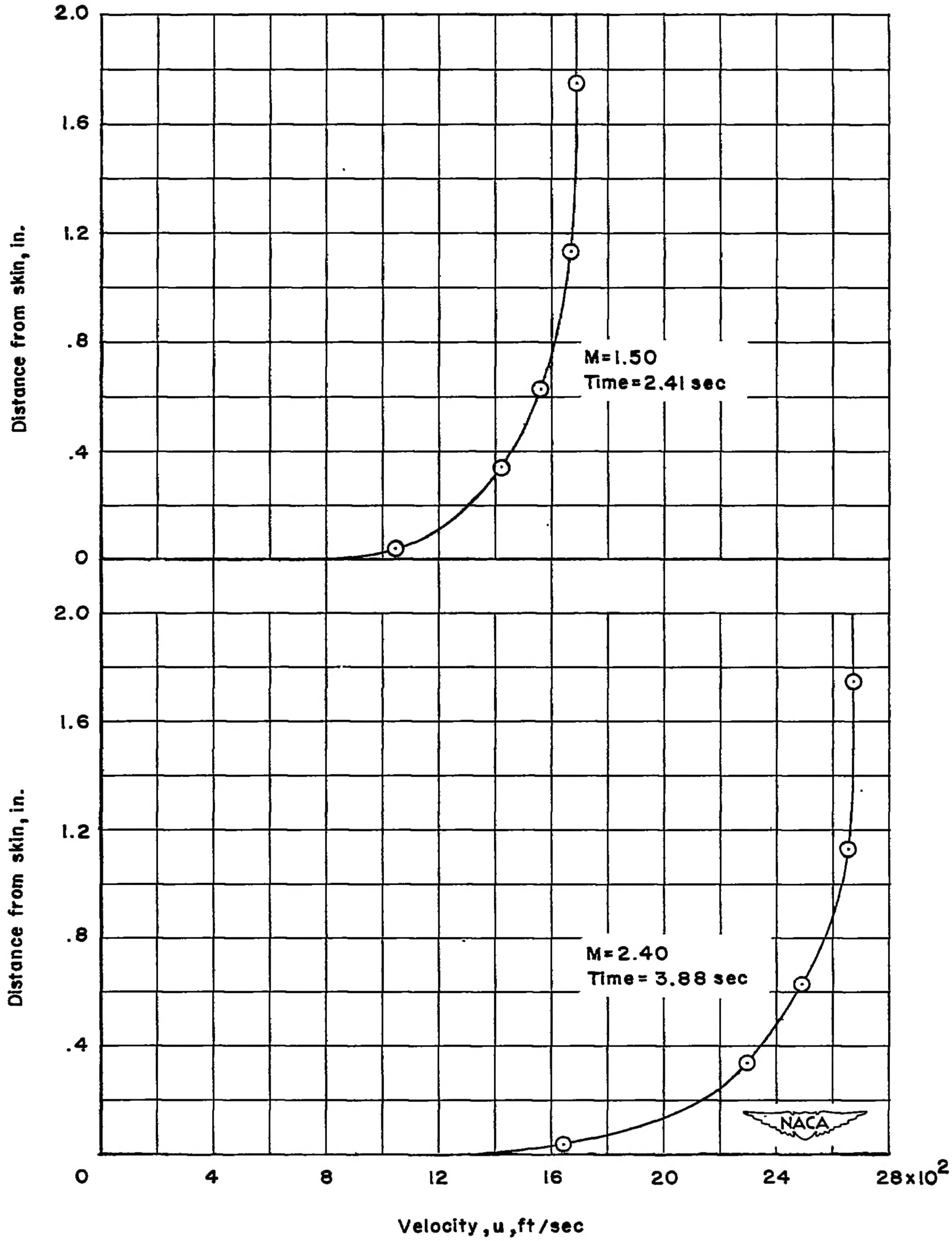

Figure 4.- Typical boundary-layer velocity profiles.

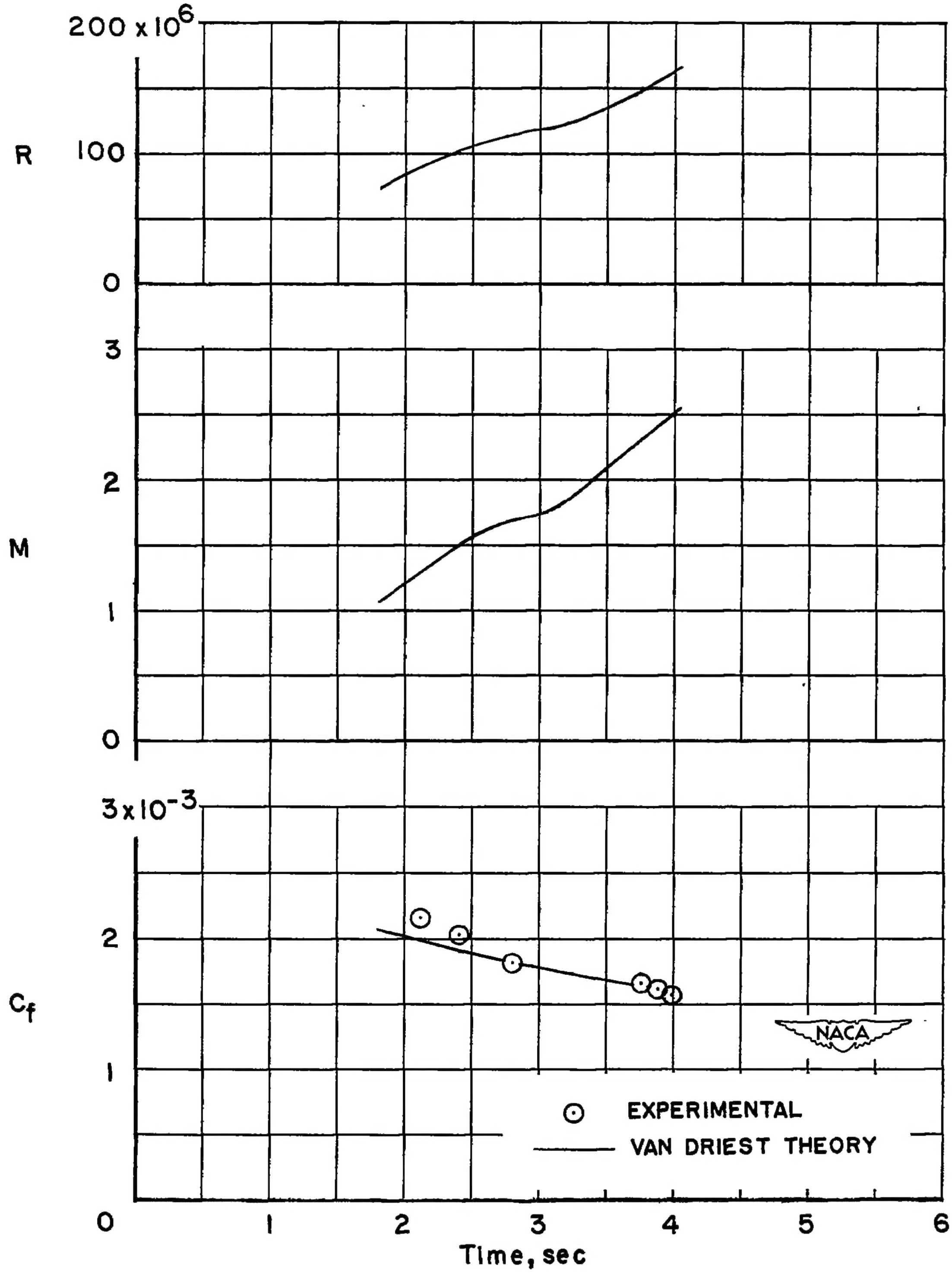

Figure 5.- Time histories of measured, average skin-friction coefficients and test conditions.

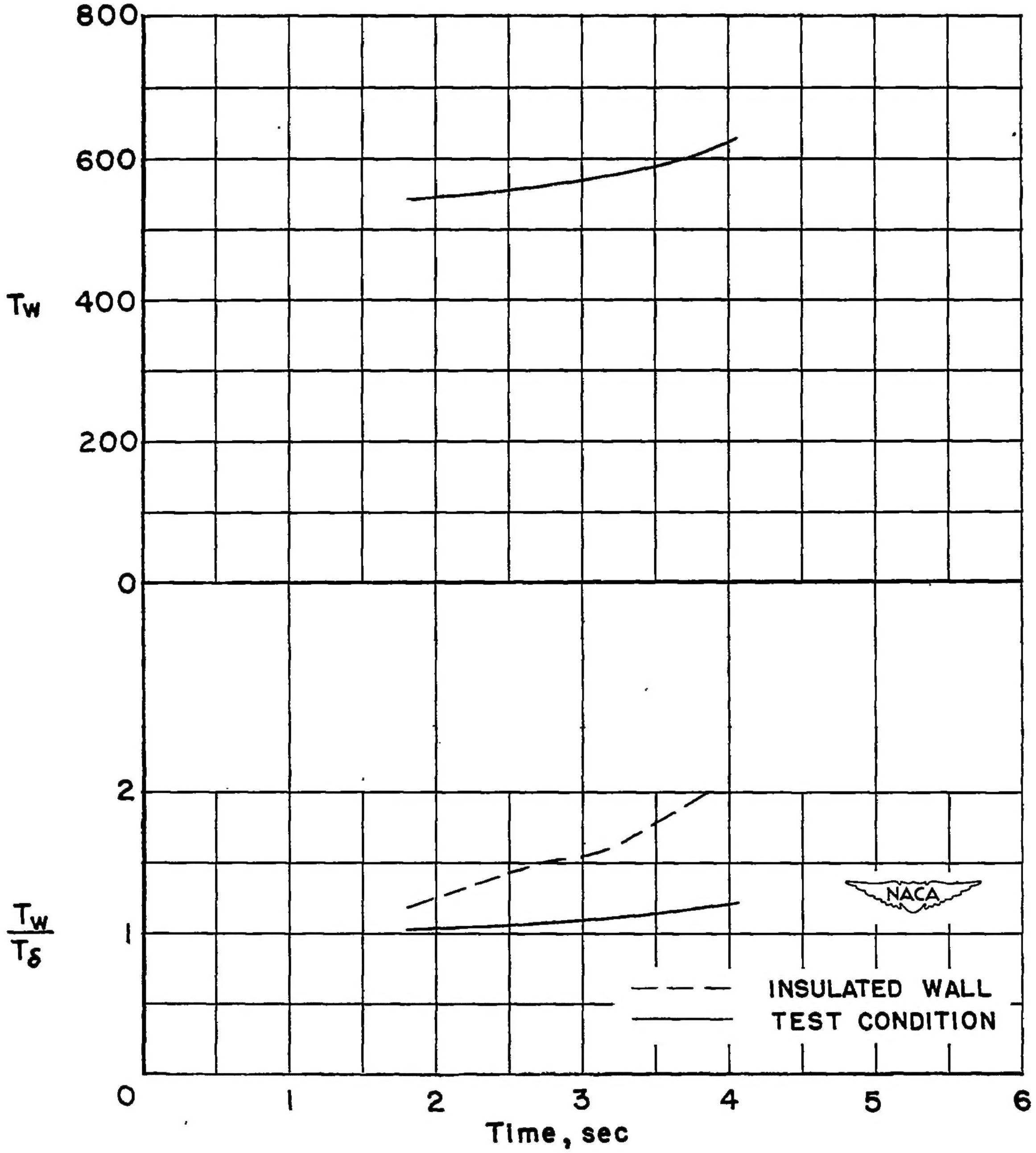

Figure 5.- Concluded.

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